Electricity and MAGNETISM

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ELECTRICITY AND MAGNETISM

by Verne N. Rockcastle

Last spring in western New York a severe ice storm coated power lines, telephone wires, and tree limbs. Many wires broke, cutting off electrical service to homes and factories. Although the electricity was off for only a few hours, it showed what life without electricity might be like. In my own home the lights, refrigerator, stove, freezer, television, radio, washer, and furnace were off. Electric clocks stopped. There was no telephone service to report broken wires. When a neighbor pushed the doorbell, nothing happened. It, too, was electrical. Food, as well as dishwater, was heated in the fireplace. Homes with electric water pumps were even without water. Local stores were sold out of flashlights, cells, and candles. The pumps at gas stations would not work. Indeed, it was almost like living 100 years ago! What a relief when "power" was restored!

The study of electricity is not nearly so old as many of our sciences. Only 200 years ago Benjamin Franklin was experimenting with his kite and key. Do you know the story about him? It would be worth while and interesting to read about his experiments. A little more than 100 years ago scientists found that electricity and magnetism were related. Less than 100 years ago people had no electric lights, telephones, or radios. And when the parents of most of you readers were young, there was no television! The story of how electricity and magnetism working together made possible our modern electrical appliances is a fascinating one. You will certainly want to find out more about such famous experimenters and inventors as Thomas A. Edison, James Watt, Michael Faraday, Alexander Graham Bell, Hans Christian Oersted, Elihu Thompson, and others.

ELECTRIC CHARGES

Little Lightning

Have you ever walked across a rug at home and received a slight shock when you turned on a lamp? Did you wonder whether the shock came from the electricity that lighted the lamp? You can answer this question for yourself by some experiments at home or in some room at school where there is a woolen rug. Imagine that you are a new Benjamin Franklin experimenting with lightning—little lightning. Your little lightning is the result of what we call *electric charges*.

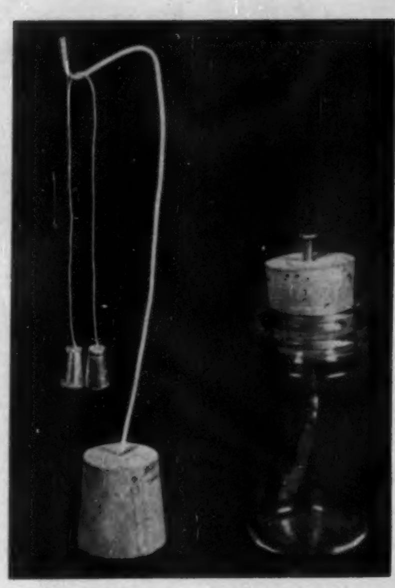
On a day when the air is dry (clear, cold days are usually dry), and you are wearing leather-soled shoes, scuff across a rug and touch the metal plate of a wall switch. (Do not touch electric sockets; they are too dangerous for you to experiment with.) Do you feel, hear, or see anything happen? Does it happen *before* or *after* you touch the object? If you can feel and hear something, but cannot see it, try experimenting in a darkened room. Place several objects on a table and touch (or nearly touch) each after you scuff across the rug. Do you get any reaction from a needle? a penny? a large nail? a metal baking pan? a piece of paper? a book? the table itself? What happens when you scuff and then touch another person? By experimenting with many different objects you can find which give you little shocks and which do not.

Cut a piece of unused carbon paper about 2 inches square. Tape this over the metal switch plate with which you have been experimenting. Now scuff across the rug and try to make a bright spark near the center of the carbon paper. When you have made several bright sparks, remove the carbon paper and examine it carefully with a magnifying glass. Do you find tiny holes in the paper? These holes were *burned* through the paper by your little lightning! If your little lightning can burn through paper, can you see how real lightning can cause fires?

Shock or no shock?

Scuff toward the switch-plate again, but this time do not touch it with your fingertip. Instead, use various objects held in your fingers. Try a nail, a spoon, a penny, and a piece of wire. Can you make sparks or get little shocks with each of these? Elec-

tric charges that cause little shocks and little lightning move through some materials easily. So these materials are called *conductors.* Now try a pencil, a rubber band, a drinking glass, and a comb. Do shocks or sparks result from any of these? Materials like these that make it difficult for electric charges to move are called *insulators.* You now know one way to test a material to find out for yourself whether it is a conductor or an insulator. Try "scuff-testing" common materials around your home or school. Keep a record of your results. Does your list of conductors contain any materials that are not metal? Can you find any insulators that are made of metal?



Two foil "leaves" when taped to a nail driven through a cork make an electroscope, too

Two kinds of charges

Find a lamp that has a pull-chain switch. Scuff toward the lamp and slowly extend your finger toward the chain. Does the chain move as your finger comes close to it? Hang a strip of paper about 1 inch wide (a strip of newspaper will do) from the edge of a table or the back of a chair. Scuff toward the paper and move your fingertip close to the free end. Does the paper move toward your finger? Comb your hair briskly. Is your hair attracted to the comb when you bring the comb close? Does an unused comb attract hair as well as the one you just used?

A simple electroscope that you can make for yourself will help you understand what you have seen. String two kernels of puffed wheat on a 10-inch piece of thread and hang them from a simple support such as that shown above. (They will work better if each is first wrapped in a small piece of gum-wrapper foil.) The kernels should hang close to or touching each other. Comb your hair several times with a hard rubber or plastic comb. (Most combs are made

from these materials.) Move the comb near the kernels of puffed wheat. Can you see the kernels first move toward the comb and then jump quickly away when they touch it? Comb your hair again and bring the comb near the kernels. Do they now move toward or away from the comb? What happens if you touch them with your finger?

Comb your hair again and touch the foil-wrapped kernels. Do they spring away? Now rub a dry pop bottle briskly with a silk scarf. Move the bottle near (but not touching) the kernels. What happens? Bring the comb near (but not touching) the kernels. Can you see that the comb and the glass have opposite effects on the kernels? (Remember that dry days are best for your experiments.)

You probably know that atoms are tiny particles of matter much too small to be seen. Perhaps you did not know that in any atom there are at least two kinds of *electric charges.* One kind moves about easily and is called a *negative* charge. The other kind moves with more difficulty and is called a *positive* charge. Usually there are about the same number of positive and negative charges. Since you are made of atoms of many kinds, much of *you* consists of electric charges! Much of the rug, the lamp, the comb, the paper, and the puffed wheat consists of electric charges.

Those Restless Charges!

They move at a touch

When you scuff across a rug, or comb your hair, you separate some negative charges from positive ones. If you take negative charges away from the rug you become *negatively charged,* but you leave the rug *positively charged.* Can you see why? When a comb removes a negative charge from your hair what is the charge on the comb? on your hair?

Touching the foil-wrapped puffed wheat with a charged comb transfers some of the negative charges to the kernels. Such a transfer of charges from one object to another is called *conduction.* The sparks you may have observed from scuffing result from conduction of electric charges through the air. Conduction occurs best through such materials as those in your list of conductors (page 5), but sometimes there is conduction in materials that are not good conductors. The air is an example.

They push and pull

Touch both kernels with a charged comb (charge them by

conduction). Can you see that they *repel* (push away from) each other? A glass rubbed with silk, however, attracts these charged kernels. By experimenting with your puffed-wheat electroscope, you will learn that *like charges repel each other, but unlike charges attract each other.*

When you scuffed toward a pull-chain on a lamp, it was attracted to you. The paper strip (page 5) also moved toward your charged finger. Although neither the chain nor the paper was charged, both *appeared* to be when your finger approached. Let's try to learn why. Remember that objects usually have both positive and negative charges and these are nearly equal in number. When your charged finger approached a paper strip, some of the charges like those on your finger moved to the opposite side of the paper. Can you explain why? (Like charges repel!) This left the side of the paper toward you oppositely charged. The diagram of a piece of paper and a charged comb shown below may help you to understand this. Which charge is nearer the comb in the diagram? Will the piece of paper move? Which way?

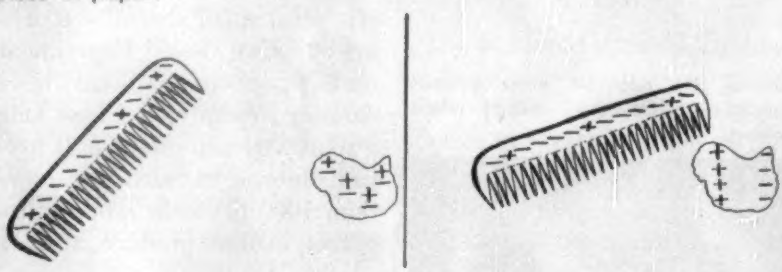
It's hard to "fence" them

The repelled charges on the paper leave it when there is some way to escape. Some escape through the air. Others escape to the table top, and so on. Touching your finger to the paper also provides a convenient path for their escape. This path of escape is commonly called a *ground*, probably because the ground is able to lose or absorb charges easily.

They can be sorted

You have learned how a charge can be transferred from one object to another by conduction. There is another way to

Can you see why a charged comb helps to separate the charges on a nearby piece of paper?



charge objects. Place a tin can on a good insulator such as a block of paraffin. Bring a charged comb near the can, but not touching it. What happens to the negative charges on the side of the can nearest the comb? Ground the side of the can farthest from the comb. (Your finger can ground it.) Where do the negative charges go? First remove your finger and then remove the comb. How does the charge on the can compare with the charge on the comb? This is called charging by *induction*. You did not need to touch the can with the comb. (That would be conduction.) But you had to provide a path for the escape of some negative charges from the can. Your finger did that.

Fun With Your Charges

The picture below shows a device that you can make to produce a charge by induction. It is called an *electrophorus* (e-lek-troff'-or-us). Stretch a piece of rubber sheeting (a piece of *red* inner tube will do) across a board and tack it along the edges. Over this lay a plastic sheet such as a plastic vegetable bag or a typing plate from a mimeograph stencil. Now place two rubber bands around a metal baking pan, pie plate, or cake pan. Rub the plastic sheet briskly with your hand. Lift the pan by the rubber bands and place it on the plastic sheet. Ground the inner surface of the pan with your fingers. If you now lift the pan by the rubber bands, it will be highly charged —with a charge opposite that of the rubber sheet.

If you bring the charged pan close to, but not touching, a faucet, a radiator, or some other large metal surface, you may see a bright spark jump between the two metal objects. Re-charge the pan and bring it near a tiny stream of water from a faucet. Can you explain what happens? Will a charged comb do the same thing? Recharge the pan and see whether another person can get a small shock by touching it. Can *you?* Experiment with your electrophorus in a darkened room to see how long a spark you can produce. It may surprise you to learn that more than 1000 dry cells working together cannot produce a spark

On a dry day an electrophorus produces a powerful charge when rubbed

as long as you and your electrophorus can!

Another interesting experiment with electric charges is the "electron ferry." You can make one of these from two tin cans, a pencil, a piece of thread, a thumbtack, and a block of paraffin. Arrange the materials as shown on this page with one of the tin cans grounded by a wire to a water faucet or a radiator. When you charge one of the cans by bringing your electrophorus near it, the thumb tack will begin ferrying electrons (negative charges) from one can to the other. From your experiments and reading you may have learned enough about electric charges and their behavior to explain why the electron ferry works. If you can discover some other interesting things to do with electric charges, I should like to hear about them.

Electric charges remain for many minutes on objects when the air is cold and dry, but pass off charged objects readily when the air is moist. Moisture acts as a conductor of electric charges. It is also difficult to keep a pointed object charged, as you can see for yourself. Holding a needle between your fingers, scuff across a rug and touch a metal lamp or a radiator. Can you see, feel, or hear anything?

Can you make an electron ferry produce an electronic tinkle?

Try it again, touching the metal ground with your finger. Can you see, feel, or hear a difference?

With a bit of adhesive tape, fasten a needle to the pan of your electrophorus. Charge the pan and try some of the experiments described on preceding pages. Do they work as well as before? Can you easily keep charges on an object when it has a sharp point? Can you see why lightning rods help to prevent an accumulation of charges on houses and barns so that a giant spark (lightning) is not so likely to happen?

Electric Charges—Problem Children

The lightning with which you are familiar is much like a giant spark. When the charge in a cloud is unlike that of the earth, and strong enough, a huge spark may occur. Lightning is one of the most fascinating displays of electric charges in rapid motion.

Provided you are in a safe place such as a steel-topped automobile, you should spend some time observing nature's most thrilling electrical display.

Electric charges produce some interesting practical problems. Gasoline trucks use various devices to ground charges that may accumulate on the truck. What might happen if charges on the truck produced a spark? The wire that projects from the road at toll-gates grounds the charges on your car so the toll collector will not be shocked. Printers are sometimes bothered by sheets of paper sticking together so that more than one sheet goes through the press at a time. Perhaps the people who mimeograph your school papers have the same problem. Because sharp points can collect charges as easily as they can lose them, large printing machines are often equipped with needlelike points that ground the charge that the paper may have as it goes into the machine. Sparks from electric charges may cause destructive explosions in such dusty places as flour mills and hemp factories. Or they may be just a nuisance by shocking you on dry days. They may even be used to collect smoke particles in large chimneys. By observing, reading, and experimenting you can learn much more about the interesting problems and uses of electric charges and little lightning.

CURRENT ELECTRICITY

The electricity that is used to heat and light your home is only a little different from the charges with which you have been experimenting. Instead of an uneven movement of groups of charges, it is a steadily moving stream of charges. It is called *current electricity*. Current electricity is more easily produced than "little lightning." It can be moved easily along definite pathways (wires) to lamps, washers, radios, and the like. You might think of current electricity as electric charges that have been "tamed."

Cells and Batteries

One common source of current electricity is the flashlight "battery," more correctly called a *cell*. Cells such as those shown on page 11 are called "dry" cells because there is no liquid to spill if they tip over. Your car *battery* (a battery contains several cells)

is made of several wet cells that contain a liquid that can spill.

With a hacksaw cut through a worn-out flashlight cell. Can you see the outer zinc case? the brass-tipped carbon rod in the center? the moist black paste between the rod and the case? Is this cell really a dry one, or is it a moist cell? An insulating leak-proof material covers the top of the cell. When a conductor, such as a copper wire, connects the carbon rod and the zinc case, an electric current is produced. This electric current is a steady flow of negative charges (electrons).

Size and strength

The amount of "push" that a cell gives its electrons is called *voltage*. When we say that a dry cell has 1½ volts, or that a car battery has 6 volts, we mean that the "push" given the electrons in a car battery is four times (1½ ×4) as strong as it is in a dry cell. It may surprise you to learn that the "push" or voltage of a pencil flashlight cell is just the same as that of a big dry cell. The difference between them is that the big dry cell can work much longer than the small cell. It can send more electrons at once than the small cell can, but the little one is just as strong as the big one. Each cell shown

Smallest or largest—only 1½ volts

above has only 1½ volts.

Some persons think that all cells or batteries will shock them if they touch the terminals. You can see for yourself that a dry cell is harmless. Pick up a small flashlight cell in your bare hands. Touch the brass tip and the bottom of the case at the same time. Does anything happen? Try a larger flashlight cell, and finally a No. 6 dry cell, like the largest one in the picture. Can you get a shock by handling a single cell? Of course not! A battery of many connected cells is something quite different, but even most batteries, including the one in your car, cannot shock you so much as can scuffing across a rug.

The wet batteries (storage batteries) that are used in cars are usually either 6-volt or 12-volt batteries. They are made of

several wet cells, each one having two different kinds of lead plates immersed in dilute sulfuric acid. If you should tip over one of these batteries, the acid might spill and cause damage. Without acid the battery would not work. Storage batteries are much heavier than dry cells because lead is used in their plates. They are also more expensive than dry cells. But, storage batteries have a special value. They can be re-charged and used again many times. This makes them particularly useful for powering the small electric motors that start engines. The batteries weaken slightly when they start an engine, but the engine soon re-charges the batteries to full strength. Why do you suppose storage batteries are not used in toys and flashlights? Dry cells can sometimes be revived by puncturing the case and soaking the cell in salt water. This, however, is temporary and does not bring the cell back to full strength. When a dry cell wears out, it is best to buy a new one.

D.C. and A.C.

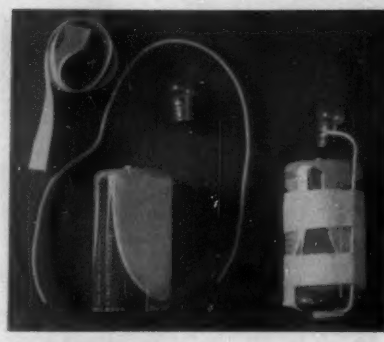
Normally a cell (or battery) acts like a one-way electric street. Electrons normally move only in one direction through it. Such a current is called *direct current*, abbreviated D.C. Later you will learn about another kind of current that is not a one-direction current and is not supplied from cells or batteries. It is called *alternating current* (A.C.) and is the kind used in our homes.

Simple Circuits

Open to traffic

The path which current electricity follows is called a *circuit*. If the electricity follows a complete path back to its beginning without interruption, the circuit is said to be *closed*. If a gap in the circuit prevents the electricity from flowing in a complete path, the circuit is called an *open* one. You can easily illustrate closed and open circuits. Arrange a flashlight "battery," a single-cell flashlight bulb, a 6-inch piece of copper wire and some adhesive tape as shown on page 13. (A 2-cell bulb will work but will not produce as bright a light as a single-cell bulb.) Make sure that an inch or two of each end of the copper wire is scraped free of its covering or coating. If you leave a gap between the base of the bulb and the tip of the cell will the bulb light? Now press the base of the bulb against the metal tip of the cell. What happens? You can see that the

circuit is open when the bulb does not touch the cell, and is closed when the bulb does touch the cell. When the bulb touches the cell, electricity can flow from the cell through the wire and the bulb and back to the cell again. Will electricity flow through the bulb if there is a gap in the circuit?



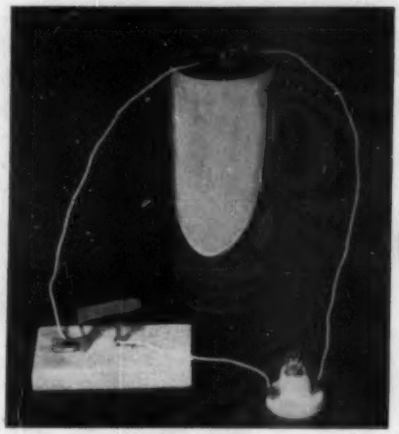
A wire, a bulb, a cell, some tape, and presto—an electric tester

Bottlenecks

Stick a small piece of adhesive tape over the tip of the cell and press the bulb against it. What happens? Remove the tape and press down the bulb. Does electricity flow through the tape? Try a piece of rubber band or balloon, a piece of plastic (Scotch tape will do), and a piece of paper or cloth. Do they allow electricity to pass between the bulb and the cell? Now try a penny, a piece of tinfoil, the blade of a knife. Does the bulb light when each of these is placed between the bulb and the cell? Materials such as rubber, plastic, paper, and cloth that hinder the flow of electricity are called *insulators*. Those such as the penny, knife blade, and tinfoil are called *conductors* because they provide easy pathways for an electric current. With your electric tester, learn which common materials around your home and school are insulators and which are conductors. Keep a record of your findings. What do you find out about wood, cloth, aluminum, chalk, leather, a dime, a dollar? Can you find the insulator on an automobile spark plug? On a power pole? You may notice, too, that most electric wires are covered with some sort of insulation. It may be enamel, rubber, waxed thread, plastic, or a combination of these. Re-wire your bulb and cell with a piece of insulated wire that you have not scraped free at the ends. Can you see how insulation can hinder as well as help in an electric circuit?

Stop lights

So far you have had to press a bulb against a cell or touch two wires together to close a circuit. A better way to do this is



This circuit is open. How would you close it?

to use a switch. The picture on this page shows a very simple switch made from a piece of a "tin" can. Can you see how pushing the top of the switch against the nail below closes the circuit and makes the bulb light? This is how a doorbell switch or push-button works. Push-buttons may have fancy cases, but they all consist of two pieces of springy metal that can be pushed together to close a circuit. Can you figure out some way to keep your switch closed without holding it?

It would be inconvenient to have to hold a button down all the time you wished to have light, heat, or music. So switches have been designed to keep a circuit closed or open without being held. The knife switch is an example. A commercial knife switch and a simple knife switch that you can make from some scrap metal, a piece of stout wire, a brass paper fastener and a cork, are shown on page 15. This is only one type of many that you use at home or at school. The switch that controls ceiling lights and some base plugs usually has a spring to snap the switch closed or open. (In some, a little puddle of mercury in a capsule is tilted back and forth to close or open the circuit silently.) Cross-bolt and pull-chain switches are often used on table lamps. Knob switches turn on and off radios, phonographs, and television sets. A push-button switch starts many cars. You may wish to make a list of the kinds of switches used around home or school. Or you may wish to start a collection of discarded switches. By taking some apart you can learn much about how circuits are controlled. Remember that nearly every electrical appliance has a switch of some sort.

Circuits That Multiply

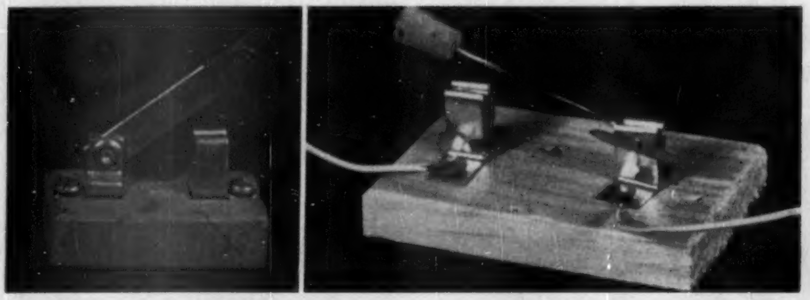
Sometimes one cell is not enough to light the bulb you are trying to use, or perhaps you want a stronger light than a single cell can produce. You

know that most flashlights contain more than one cell. By unscrewing the back of an ordinary flashlight you can see how the cells are placed in the case. What will happen if the cells are pointed in the opposite direction? What will happen if the cells are placed point-to-point? base to base? Remove one cell from the case of a two-cell flashlight and, without replacing the back of the flashlight, press the blade of a screwdriver (any conductor will do) against the bottom of the remaining cell and against the body of the case? Now close the switch. Does the bulb light? Replace the second cell and close the switch. Is the light as bright with one cell as it is with two cells?

Cells that are arranged so that the voltage or "push" of one is added to that of the next (as in an ordinary flashlight with more than one cell) are arranged in *series*. The picture on page 20 shows three cells connected in series. Cells arranged in series do not necessarily last longer than single cells, but together they can produce as much voltage as the sum of the individual cells. If each cell in a 2-cell flashlight has 1½ volts, the two working in a series can produce 3 volts. A 5-cell flashlight can light a 7½ volt bulb and so on.

If a continuous low-voltage electric current is needed, then the cells can be connected in parallel as shown on page 16. Cells connected in *parallel* have no greater voltage than a single cell. Electric current in the lamp is "shared" by the cells so that each cell works only a fraction as hard as it would if it worked alone. Two cells connected in series would make a bulb glow twice as bright as a single cell would. Two cells connected in parallel would make it glow

Both the commercial knife switch (left) and the homemade one (right) keep a circuit open or closed



twice as long, but no brighter than a single cell would.

Some batteries that operate flash units for cameras are made up of many tiny dry cells connected in series. Some of these "power-packs" produce more than 500 volts! How many dry cells would it take to make such a battery? Most car batteries are made of several 2-volt wet cells in series. If a car battery has three cells, it is a 6-volt battery. If it had six cells, what would be its voltage? What is the voltage of *your* car battery?

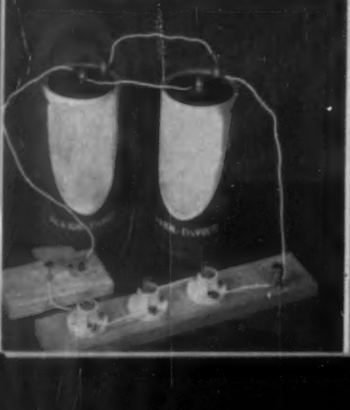
Bulbs as well as cells can be connected in series or in parallel. With circuits similar to the ones on this page, you can add extra bulbs to see what each additional bulb does. When you use only one dry cell, are two bulbs in series as bright as one? What happens when three are used? four? To two bulbs connected in series, add two cells connected in series. Now replace the cells with two connected in parallel and connect them to the two bulbs. What differences do you see? By connecting several cells and several bulbs in various combinations you can learn a great deal about series and parallel circuits.

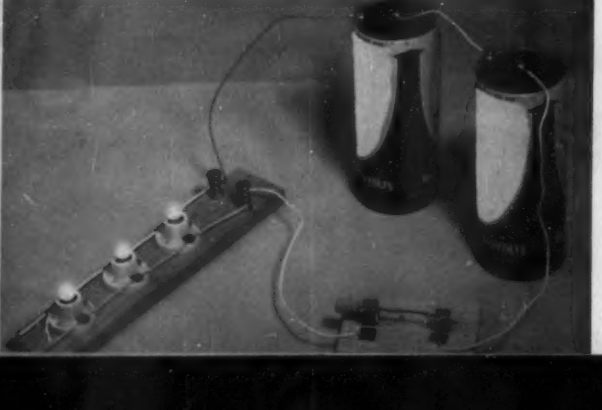
Unscrew one of the bulbs connected in series. What happens? Some Christmas tree lights use this arrangement. Have you seen a whole string of lights go out when one bulb "burns" out? Now remove a bulb from a parallel circuit. What effect does this have on the other bulbs? If you unscrew a bulb from a light socket in your home, do the rest of the bulbs in the room go out? From what you have learned can you tell what kind of a circuit is commonly used in your home and school?

Plugs and Sockets

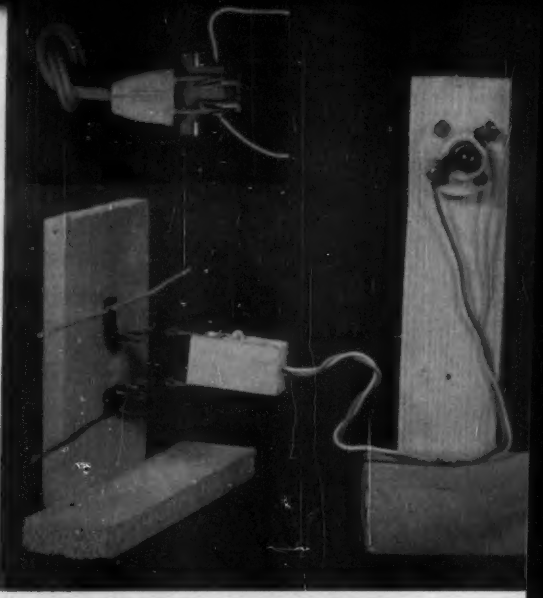
In your home and school the two wires of ordinary circuits

The cells at the left are in parallel, the bulbs in series. The cells at the right are in series, the bulbs in parallel. Which bulbs will be brighter? Which circuit is open?





are attached at intervals to wall sockets. At these sockets appliances may be connected by "plugging in." Each prong (how many prongs on a plug?) is connected to one of the wires of the appliance. Each half of the socket is connected to one of the circuit wires. When you plug in a lamp or a vacuum cleaner, the prongs of the plug touch the metal sides of the socket. A plug and a socket partly cut away, and a simple plug and a socket that you yourself can make from wire, some tin-can metal, and some tacks are shown on this page. With such simple plugs, you may be able to make a model wiring system that will help you and your classmates understand how various electrical appliances are plugged into a circuit. (Remember that *you must not experiment* with the wall plugs at home or school; the electric current they supply is too dangerous for this.)



A plug joins the two wires of an appliance to the two wires of a socket

Alternating Current

There are many reasons why direct current cannot be transmitted easily and cheaply from the power station to places where electricity is used. Instead, a different type of current called *alternating current* is produced. Alternating current is a to-and-fro movement of electrons in a conductor. There is a current when the electrons move, but there is no current at the instant the direction of movement changes. Bulbs that are lit by alternating current glow brightly as the electrons move in one direction. Then the lights dim and "go out" as the electrons slow down, stop, and reverse their direction of movement. Years ago, some lights were on 25-cycle current. They flickered noticeably. But today you cannot see most lights flicker. One reason is that the white-hot wire in incandescent bulbs cools very little between current changes. Another is that all modern cur-

rent electricity is 60-cycle current and 60 cycles a second (120 stops and starts) is too fast for your eyes to detect.

You can see the effects of a 60-cycle current if you wave a light-colored pencil back and forth beside a fluorescent light. The room should be dark except for the fluorescent light. When the light comes on, you can see the pencil but in that dark fraction of a second while the light is off you see nothing. The pencil keeps moving and then in a twinkling the light is on again and you see the pencil in a slightly different position. Can you describe what you see? Try the blade of a table knife or some other thin object. Is the result the same?

Most electric clocks depend upon the number of alternations of current each second. When the alternations are 60 times each second, the clocks keep correct time. If the alternations should decrease to 59 times a second, most electric clocks would run too slow. If the alternations increased to 61 times a second, the clocks would be fast. Can you see how important it is to keep alternating current at a constant rate of 60 cycles per second?

Home Appliances

Hot wires

Touch a small wire to the terminals of a dry cell or a flashlight cell for a few seconds. (Do not connect the wire and the cell—it will weaken the cell.) What do you feel? What you just felt is used in many home appliances. The main difference is that you used a 1½-volt direct current, while your home appliances use 110-volt alternating current.

In most electric lights a tiny wire connects the 110-volt wires leading to the socket. It becomes white-hot when the switch is closed. When Edison experimented with his electric light, he first used carbonized thread and later bamboo fibers. It took years of research and much money to develop the bulbs you now buy at most stores.

Turn off that light!

The wire in small, dim bulbs is finer than the wire in very bright bulbs. On the end of an ordinary light bulb you usually can see printed some numbers and letters such as 40W, 60W, 75W, or 100W. These numbers tell you that the bulb is a 40-*watt* bulb, a 60-*watt* bulb, and so on. If you use a 100-watt bulb for one hour, you use 100 (100

times 1) watt-hours of electricity. If you have a 100-watt bulb lighted for 10 hours, you use 1000 (100 times 10) watt-hours of electricity and so on. One thousand watt-hours is called a *kilowatt-hour* and usually costs from two to four cents, depending upon where you live. If you assume that a kilowatt-hour costs three cents, how much does it cost to have all the lights in your house lit for one hour? Do you really save much by turning out a small light for a few minutes? Electricity is about the cheapest kind of power we have. While many things we buy have risen in price during your childhood, electricity has gone down in price in many localities!

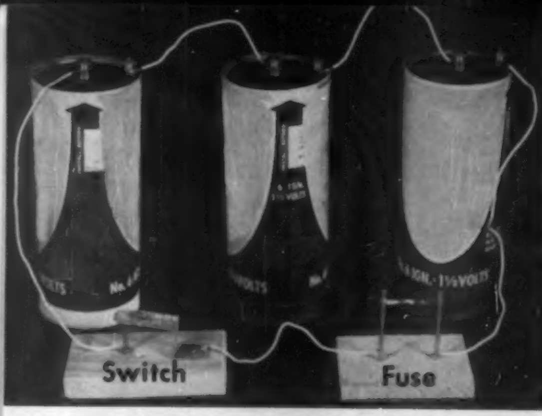
An electric toaster, a flatiron, a stove, a hotplate, a cornpopper, a waffle-iron, an oven, and a clothes-drier all work on the same principle as the electric light. In most of them, however, the heated wire is larger, carries more current, and becomes red-hot instead of white-hot. A toaster, for example, may use electricity at the rate of 1000 watts, and an electric oven on "broil" may use it at the rate of 3000 watts (as much as thirty 100-watt bulbs!).

Perhaps you and your parents can figure out how much of your next electric bill goes for each of the appliances in your home. Or, if your parents occasionally scold you for leaving a light on in your room, you can find out how much it does cost to keep a 100-watt bulb lit for an hour. Is it more or less than a penny? It is not only fun, but enlightening, to learn how much it costs for each of the appliances you use—lights, television, radio, washing machine, and the like. Your nearby electrical dealer can probably supply you with the wattage of the appliances that have motors, or the appliances on which the wattage is not indicated.

Safety Devices

Wires that melt

The current that ordinarily flows through the electrical devices in your home or school is only a small part of the current that can safely be carried in the wires. If, however, too much current flows in the main wires, even they can heat enough to cause fires. To prevent such damage, it is customary to place in the circuit some sort of safety device that will open the circuit if the "load" (current) becomes too great. One common type of safety device is a *fuse*—a conductor that will melt and open the circuit if the current exceeds a safe amount.



If the fuse melts, the circuit is immediately opened. What is the voltage on this fuse?

You can make a simple fuse and observe its operation. Connect four dry cells in series. (Remember that the inner binding post of one cell should be connected to the outer post of another cell.) Now connect your series to a switch and two nails as shown in the illustration above. Cut a strip of gum-wrapper foil 1/16 inch wide and about 1 inch longer than the distance between the two nails. Wrap each end of the foil strip around a nail so the nails are connected as shown. Be careful to keep both the nails and the foil free from dirt and grease. When you close the circuit, what happens to the foil? This is what happens to a fuse in your home when there is an unsafe current in it. A fuse blows (melts) so quickly that it is almost impossible to photograph its happening.

In your home there are usually four or more separate circuits with a fuse in each one. The bedroom lights and the bathroom lights may be on a single circuit, controlled by one fuse. If the fuse on that circuit blows (melts), all the lights on it will go out. No other circuits will be affected. You can find out which lights are on a particular circuit in your home. Ask your parent, or someone else who is wise and careful, to unscrew one fuse from the fuse box. Then you try the light switches and lamps in some parts of the house. If only one fuse is unscrewed, what must be true of lights that cannot be turned on? Perhaps you can make a list of the lights and wall sockets in your home, and the fuses that control them. Then if a fuse blows, your parents can quickly locate and replace it by referring to your fuse and light list.

Most home circuits can safely carry a "load" of 15 amperes. (An *ampere* or "amp") is a certain size of electrical current). If the current exceeds 15 amperes, the wires may heat—even become dangerously hot. So a 15-ampere *fuse* is placed in these circuits to limit the size of the current. If the current exceeds the limit of the fuse, the fuse will blow and open the circuit. If a 15-ampere fuse keeps blowing, then some-

thing is allowing more electricity to flow than the wires can safely handle. Such a circuit should be investigated by a competent electrician.

"Short" circuits blow fuses

Suppose that a circuit in your home or school supplies three 100-watt bulbs and five 60-watt bulbs. A 15-ampere fuse can safely carry this much current. Suppose, however, that one of the wires in a lamp cord accidentally touches another wire in the same cord, or touches the metal lamp socket. This may create a sort of electrical "bridge," that allows a greater current than would have been possible in the bulb alone. Such a bridge is called a *short* or *short circuit,* and allows a large current in the wires of that circuit. Without a proper fuse, this large current might overheat the wires. So fuses are important safety devices. Can you understand why it is unsafe to replace a blown fuse with a wire, a penny, or anything except another fuse of the proper size?

Overloading blows fuses too

Placing too many appliances on a single circuit may also allow too much electricity to flow. Suppose, for example, that on a circuit with a 15-ampere fuse there were a toaster, a roaster, a flatiron, a refrigerator, and two or three 100-watt bulbs. If these were all operating at once, much more than 15 amperes would flow and the fuse would blow. Persons who don't understand why fuses are used might replace the blown 15-ampere fuse with a 20-ampere fuse. If this blew, they might use a 25-ampere fuse, then a 30-ampere fuse, and so on until they found one that wouldn't blow. Doing this would place a serious overload on wires that are not meant for such a current. What should be done if fuses blow on circuits that operate several appliances at once? Disconnect some of the appliances! But circuits, such as kitchen circuits, that must supply heavy-duty appliances need larger fuses and must use larger wires.

You may wish to make a study of different kinds of fuses. Can you find the fuse in your auto circuit? Ask your parents to open the fuse box of your home and show you the cartridge fuse in the main line. Ask the school janitor to show you the large fuses in the school circuits. Perhaps the janitor or your parents can save some blown fuses from home or school for your study of electrical safety devices.

Circuit-breakers

It is a nuisance to have to replace burned-out fuses, especially since it means keeping a supply of fuses on hand at all times. So other kinds of safety devices have been invented. They are called *circuit-breakers*. (They break or open the circuit if there is too much current.) In some, springs held in place by a material that softens or melts with too great a load open the circuit. These circuit-breakers can be re-set when the load has been reduced. In others an electromagnet opens the circuit. You will learn more about electromagnets later in the Leaflet. Circuit-breakers are not often used in homes because they cost more than fuse-boxes, but you may be able to see one in your school or in a nearby factory.

The books and pamphlets listed at the end of this Leaflet tell more about simple electrical circuits and appliances. You may wish to make and do some of the things suggested in them. They will help you learn more about electricity and what it can do.

MAGNETISM

Can you tell what direction you are now facing? If you can tell, how do you know? Does the position of the sun tell you? Can you see shadows that help? Do the tree-tops bend toward the east because of prevailing westerly winds? Direction is probably not so important to you who have street signs and road maps to point the way. But what about the adventurers like Marco Polo, Columbus, or Byrd? What of the early settlers who crossed seemingly endless prairie? or planes that fly in fog and clouds? or ships that sail the oceans of the world? They must be able to tell direction. Some navigators rely on the sun or stars, but often they use some sort of *compass*.

Compasses Are Magnets

The earliest known magnet was a kind of stone that picked up things made of iron. It was called a *loadstone*. Ancient people learned that a loadstone, when suspended and free to swing, could be used as a compass. Later, stronger *steel* magnets were developed. These made even better compasses because they could be shaped into arrows and placed in portable cases. Have you seen a compass that resembles any of those

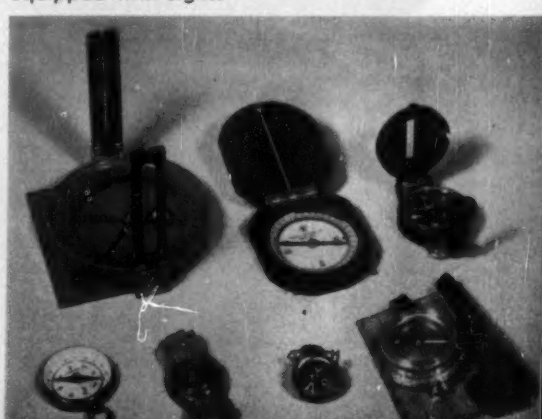
below? There are many styles of compass. Most of them use a magnetized steel needle. The needle is free to swing about a vertical pin or post so that it always points toward the north.

A simple compass

If you have a bar or a horseshoe magnet, you can make a simple compass from a darning needle. A steel knitting needle or an old hacksaw blade also makes a good compass. There are probably some magnets at your school, or you may find one in a nearby five-and-ten or hardware store. Sometimes strong magnets can be bought at junk yards for a few cents. Tie a yard-long piece of thread to the center of the needle (or saw blade). Move the needle backward or forward until it hangs level. With one hand hold the thread in place at the center of the needle. With your other hand use a magnet to stroke the needle from one end to the other. When you finish one stroke with the magnet, lift it from the needle and repeat the stroke, in the same direction and using the same end of the magnet. After a few strokes your needle will be magnetized and you can use it as a compass. Suspend it a few feet away from any iron that might affect it. Is the needle still level? In what direction does the eye point? the tip? Tap the needle so it turns. Does it return to its original position? If several of your classmates suspend magnetized needles, do all needles point in the same direction? Can you find why the needles do not hang horizontally after they are magnetized? Some of your science books or the books in your library may help you.

The magnetism in your magnetized needle (or hacksaw blade) will remain for a long time—perhaps for years. Such magnets are called *permanent* magnets. They are not really permanent, but they do retain their magnetism much longer than temporary magnets made from the soft iron used in common nails. If you repeat your experiment, using a nail instead of a needle, can you make a compass? Is your compass nail attracted by another nail brought

Seven compasses—seven magnets all pointing north. The top three are equipped with sights



near it? Can you see that soft iron does not work so well as steel for your compass needle?

A floating compass

A magnetized needle can be made to "float" on water if it is laid very gently on the surface. Sometimes a small wire cradle like the one shown on page 25 can be used to lower the needle onto the surface of water in a glass or pan. The water provides an almost friction-free bearing for the needle. If you turn the glass or pan gently, does the needle turn with it? If you turn the needle, does it return to its original position? Now touch the needle with your finger. Was it really floating, or just resting on a sort of "water membrane"?

Magnets Pull and Push

What do magnets attract?

Bring a piece of iron (a nail will do) near your homemade compass. Does the needle still point toward the north? Remove the nail and try a penny. Does the compass needle react to it? Can you find other materials that will not react to your compass or to a bar or a horseshoe magnet? Make a list of the things a magnet will attract, and a list of the things it will not attract. Try pins, needles, tacks, nails, coins, chalk, paper, buttons, and other common objects. Compare this list with the one suggested on page 5. Are good conductors always magnetic? Are materials that are magnetic always good conductors?

What attracts magnets?

You saw how your compass needle swung away from north when a nail or a knife blade was brought toward it. I know well how nearby iron or steel affects a compass. I once became lost in the Adirondacks because a useless belt axe I was wearing affected my compass. After several hours of walking and much embarrassment I had learned that a compass is only as helpful as the common sense of its user.

Magnets have poles

Lay a strong bar magnet on a paper over which you have sprinkled some tacks or wire brads. Pick up the magnet and see how the tacks are arranged along it. They cluster at the places where the magnetism is strongest. These places, usually near the ends of the magnet, are called the *poles*. The end of the magnet that tends to point to the north is called the *north pole* or north-seeking pole, and is sometimes marked with an "N."

The opposite end is the *south pole* or south-seeking pole and may be marked with an "S." Which end of your needle compass do you think is the north pole? You can find out by suspending the needle and observing its position when it comes to rest. Bring a bar magnet near your compass needle, holding the magnet so that one pole is closer to the needle than the other pole. What happens to the needle? Now reverse the bar magnet. What happens?

Magnetize two needles, suspend them a few feet apart, and mark the north pole of each with a piece of tape. What happens as you bring the two needles close together? From your experiment can you see that like poles *repel* (push away) each other, but *unlike* poles attract each other?

Magnetize a steel knitting needle with a bar magnet. Test it to identify the poles. With cutting pliers or a hack saw cut the knitting needle in two. Do the cut ends have any magnetism? Bring the two halves close together. Is the half that contained the north pole *all* north pole, or does one end of it now become a south pole? What do you think would happen if you cut the halves into still smaller pieces? Can you find any explanation for this in your reading or from your experiments?

Place a magnet under a piece of white paper and then sprinkle some iron filings or some very small brads (thin, small nails) over the paper. Can you see the pattern of the magnetism around the magnet? Tapping the paper lightly may help to form the pattern. Magnetism, you see, appears in curved paths about the poles, not in straight lines around a magnet. Magnetism does not really follow distinct lines, but it looks that way when you use materials as coarse as iron filings or nails. Some books on magnetism may help you to understand more about why your magnetism pattern looks as it does.

Permanent Magnets and Electricity

Magnetism has an interesting relation to electricity that you can easily see. Magnetize a darning needle and suspend it from a coil of wire by a thread or a rubber band as shown on page 27. Connect the coil of wire to a

The magnetized needle at the left "floats" on water. Place it there gently or it will sink

switch and a dry cell so that a current will flow through the coil when the switch is closed. Arrange the coil and the needle so they are parallel to each other. What happens when you close the circuit? Does anything happen when you open the circuit? Instead of the needle, use a small compass resting on a block of wood or a paper platform. Does the compass needle swing when a current goes through the coil? Which way does the north pole swing? Reverse the wires on the cell and close the circuit again. Does the direction of the current affect the direction of the compass needle? By trying the coil in different positions you will learn that a current of electricity in a coil acts just as a steel magnet does.

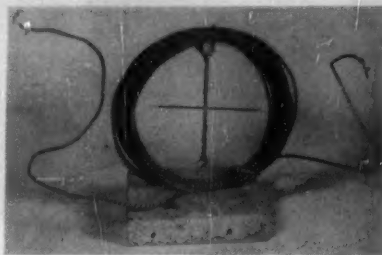
Connect two dry cells in series and repeat the experiment. Can you see that the needle reacts in the same way, but faster? Electrical measuring instruments make use of this difference in reaction. But instead of a permanent magnet that rotates inside a coil, they use a coil held by a small spring inside a powerful horseshoe magnet. A small electric current flowing through the coil magnetizes it. The permanent magnet swings the magnetized coil which stretches the spring. The stronger the current, the greater the swing of the coil and the stretch of the spring. An instrument that measures any tiny electric current is called a *galvanometer*. One designed to measure volts is called a *voltmeter*. One that measures amperes is called an *ammeter*. The science teacher in your high school can probably show you all three instruments. Can you see the tiny coils of wire and the permanent magnets in them?

Electromagnetism

A wire-and-iron magnet

A coil of wire such as you used with your magnetized needle (page 27) can be made a much more powerful magnet by wrapping it around an iron center or *core*. Wrap a long insulated wire (6 feet of No. 22 wire or No. 24 wire will do) ten times around an iron core, such as a large nail or iron bolt. Touch the ends of the wire to the terminals of a dry cell. Does your *electromagnet* pick up small bits of iron? (Does the wire heat when you do this?) Wrap ten more turns of wire around the bolt and repeat your experiment. Can you pick up more bits of iron? Try three times as many turns. What happens? Use two and then three cells connected first in series and

later in parallel. Use different numbers of turns of wire with different numbers of cells. Can you see that the strength of your electro-magnet depends both upon the number of turns of wire and on the number of cells you connect to it?



The needle of this galvanometer can be adjusted by moving it up or down in the twisted rubber band

Magnets that move

Wrap about 100 turns of fine insulated wire (No. 24 or smaller) around a 3- or 4-inch piece of glass tubing. Connect the ends of the wire to a switch and a dry cell. Place a long nail inside the tubing so that most of the nail projects from one end of the tube. When you press the switch button what happens? A brass or aluminum (or even cardboard) tube will work if you have plenty of turns of wire and grease the nail to reduce friction. Can you arrange your coil of wire (called a *solenoid)* and the movable nail (often called an *armature)* to ring a gong when the button is pressed? The picture on page 28 shows one way to do this. Gravity, or a spring that pulls the armature back to its original position when the circuit is opened, can make the armature ring a second gong. This is how two-tone door chimes work. More chimes can be added by making the armature of the first solenoid ring a chime, and at the same time close the circuit of a second solenoid. The second can ring a chime and close the circuit of a third, and so on. Each armature can ring still another chime when it returns to its original position. How many chimes do you think could be rung by one closing and opening of the switch?

Solenoids are useful to operate switches in circuits that cannot be reached by a person. Such switches are said to be operated by "remote control." Suppose that a railroad control tower operator wished to throw a switch (a train "switch," not an electric switch) at some point down the track. Years ago he would have had to go down to that point and throw the switch himself. Or he might have pushed a giant lever in the control tower that would move the track by a series of long connecting rods. Now he

Closing the circuit rings the right chime. Opening it rings the left one. Can you see why?

can push a button and let a small electric current and a powerful solenoid do the work for him. In fact, many train switches are now automatic, with solenoids operating most of the switches along the line.

You can probably find dozens of uses for solenoids in your home or school. A solenoid may operate the switch on an electric motor, turn on a light, or do any number of things. Some are used to throw switches on wires carrying dangerously high currents. Solenoids may control the valves on an automatic washing machine or on a dishwasher, the starter motor in the car, the furnace motor, and many other devices.

The picture on page 29 shows a simple telegraph sounder that you can make. Bend two nails as shown. Make one an electro-magnet by winding it with 30 or 40 turns of insulated wire. Drive the nails into a block of wood so that their heads are about ¼ inch apart. Arrange an iron hinge or hasp (the armature) as shown, and use a rubber band to hold it away from the electro-magnet. Connect the electro-magnet to a switch and dry cell. What happens when you close the switch? open the switch? You may have to adjust the rubber band or the distance between the nails to make your sounder work well. Perhaps you will want to try clicking out some codes with it.

The same sounder is shown on page 31, but this time the circuit includes the armature and one of the nails. The nails are also closer together. When the circuit is closed, the electro-magnet pulls the armature away from its nail. This opens the circuit. What happens to the armature? Can you see that the armature will vibrate back and forth between the nails as long as you

hold the switch closed? With some slight modifications this is how ordinary door bells and buzzers work. Your simple buzzer should help you understand the operation of the various buzzers you hear during the day—the buzzer or bell that tells you school is beginning or ending, the doorbell of your home (unless your home has chimes), the telephone bell, and even the electric timer on your stove or oven.

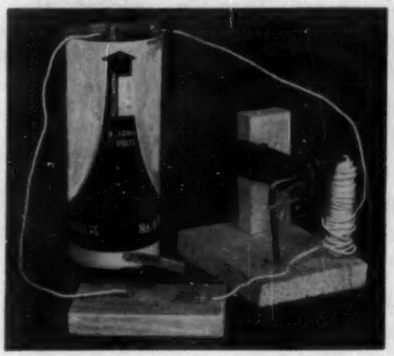
Electric Generators

You have learned that an electric current passing through a coil of wire produces magnetism. A coil of wire and a magnet can produce an opposite effect. To see this, connect a coil of wire to a galvanometer (the coil and needle described on page 27 will do). Move a bar magnet slowly back and forth through the coil. Do you see a movement of the needle of the galvanometer? Now move the magnet faster. Does the needle of the galvanometer react any differently? Put the magnet inside the coil of wire and hold it steady. Does anything happen to the galvanometer needle? When the needle of the galvanometer moves you know that some electricity is flowing through the instrument. Whenever a magnet moves near a coil of wire some electricity is produced. The more turns of wire in the coil, or the stronger the magnet, the more electricity is produced. This is the principle of a *magneto.* Many outboard motors, gasoline-powered lawnmowers, and chain saws use magnetos to supply electricity to the spark plugs. The old-fashioned crank telephones used magnetos to generate electricity. If you are lucky enough to find an old crank telephone to experiment with, you can learn much about how electricity is produced.

Transformers

You have seen how a bar magnet and a coil of wire can produce an electric current. An electro-magnet works as well as

When the switch is closed, the hasp is pulled to the right to make a sharp click. How does it return?



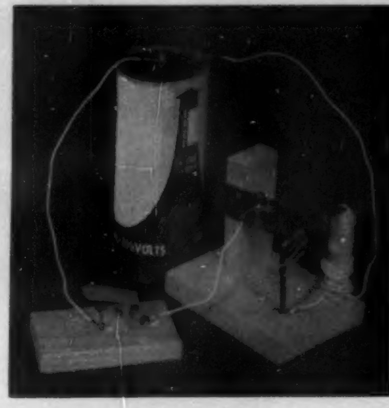
a bar magnet and is more convenient in many ways, as you will see. Wind 30 or 40 turns of wire around an iron core such as a large bolt. Then wind a separate wire right over the first, using about the same number of turns. Now you have an iron core surrounded by two separate coils of wire. Connect one coil to a switch and dry cell. Connect the other to your galvanometer. When you close the switch what happens to the needle of the galvanometer? Open the switch and see what happens. What happens if you keep the switch closed or open for several seconds? By opening and closing the switch very fast you could produce an electric current in the second (secondary) coil. It would be much like the current in the dry cell coil (primary) except that the current from any cell is a steady one. The current produced in the second is a vibrating one. It vibrates at the same rate that you operate the switch.

If you put twice as many turns on the secondary as you put on the primary, there will be twice as much voltage in the secondary as in the primary. Suppose the secondary had 100 times as many turns as a dry-cell primary, what would its voltage be? Remember that a single dry cell can produce only 1½ volts, so if you used one dry cell on the primary you would get 100 times 1½ volts (150) on the secondary. In autos a 6-volt battery can produce a spark plug voltage of several thousand volts by having many, many more turns on the secondary than on the primary.

Your coils have been using direct current. If you could use alternating current which changed direction 60 times each second, and did this hour after hour, you would have a *transformer*. A transformer uses alternating current on the primary and also produces alternating current on the secondary. If the number of turns on the secondary is greater than on the primary, the transformer increases the voltage. If there are fewer turns on the secondary, it decreases the voltage. Can you tell which coil has the greater number of turns in an electric-train transformer? (House current is 110 volts; the train operates at from 5-15 volts.) The large black boxes that you see on certain power poles are step-down (decrease the voltage) transformers. They reduce the voltage of high-tension power lines from several thousand volts to the 110 volts of your house current. Perhaps you have noticed that three wires instead of two lead to some

houses. With three wires it is possible to obtain 220 volts for such things as electric ovens, stoves, hot-water heaters, and clothes-driers.

In this Leaflet you have read about some of the simple effects and uses of electricity and magnetism. You may wish to read about even more uses of electricity: electric motors and generators, electron tubes in radio and television, electron microscopes, and the whole new world of high-energy particles. Much could be written on any one of these topics. As you read and experiment you will realize that electricity and magnetism present one of the most fascinating and unexplored areas in all of science. *Respect* electricity, but be *curious* about it, and you shall be rewarded with the delightful discoveries that await any eager young scientist.



Compare this circuit with the one shown on page 29. What happens when the hasp moves to the right?

ADDITIONAL ACTIVITIES

1. Construct a simple fire alarm, using a circuit like that shown on page 14. Replace the bulb with a small buzzer. Bend the switch to stay closed. Place a tiny bit of wax in the switch to keep it open until heated. (Is wax a conductor?)

2. Construct a simple burglar alarm that will ring a buzzer when a door is opened. Attach one-half of the switch to the door jamb, the other half to the door, so that the circuit will be closed when the door is opened.

3. Construct an electromagnetic crane. Wrap 50 to 100 turns of fine enamelled wire around an iron bolt. Suspend the bolt so that it can be raised or lowered. Attach a switch and a cell. Close the switch to pick up a load of iron (nails, thumb-tacks). Open the switch to release the load.

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